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West Bengal State University

PG Syllabus (NEP) in Physics
(Effective from 2026-'27)

Programme: M.Sc. in Physics (2 Years Course)

/Minor
Eligibility: 3 years B.Sc. (Honours/ Major) in Physics

Programme-specific outcome

The M.Sc. Programme in Physics trains a learner beyond the horizon of basic level Physics taught at the undergraduate level. Primary goal is to develop fundamental understanding in the core areas as well as specialized skill in the advanced areas of modern physics so as to enable the learner to actively participate in R&D programmes in Physics and related subjects at a professional level. Besides nurturing the research potential of a learner, special emphasis is given in cultivating the teaching abilities and problem-solving skills also.

M.Sc. Syllabus (NEP) in Physics (2 Years)
Draft recommended by the PGBoS in Physics

Semester-1

Sl. No.	Course Code	Course Title	Credit
1	PHS2PCOR01T	Mathematical Methods of Physics	4
2	PHS2PCOR02T	Analytical Dynamics	4
3	PHS2PCOR03T	Introductory Quantum Mechanics	4
4	PHS2PCOR04T	Elements of Statistical Physics	4
5	PHS2PCOR05P	General and Computational Lab I	4
6	PHS2PAEC01M	Machine Learning and its Application in Physics	2

Semester-2

Sl. No.	Course Code	Course Title	Credit
1	PHS2PCOR06T	Classical Theory of Fields & Electrodynamics	4
2	PHS2PCOR07T	Condensed Matter Physics	4
3	PHS2PCOR08T	Applications of Quantum Mechanics	4
4	PHS2PCOR09T	Exposure to Astronomy and Material Physics	4
5	PHS2PCOR10P	General and Computational Lab II	4

Semester-3

Sl. No.	Course Code	Course Title	Credit
1	PHS2PCOR11T	Elements of Spectroscopy	4
2	PHS2PCOR12T	Advanced Quantum Mechanics	4
3	PHS2PCOR13P	General and Computational Lab III	4
4	PHS2PDSE01T	(a) Advanced Condensed Matter Physics I (b) Astrophysics I	4
5	PHS2PCOR14M	Seminar Presentation	4
6	PHS2PSEC01M	Physics Teaching Skill	2

Semester-4

Sl. No.	Course Code	Course Title	Credit
1	PHS2PCOR15M	Problem Solving Techniques in Physics	4
2	PHS2PDSE02T	(a) Quantum Field Theory (b) Non-linear Dynamics	4
3	PHS2PDSE03T	(a) Advanced Condensed Matter Physics II (b) Astrophysics II	4
4	PHS2PDSE04P	(a) Advanced Condensed Matter Physics Lab (b) Astrophysics Lab	4
5	PHS2PCOR16M	Project Literature Review	4
6	PHS2PCOR17M	Project Dissertation	4

For Detailed syllabi: see overleaf

Detailed Syllabi:

Semester I

PHS2PCOR01T: Mathematical Methods for Physics 60 Lectures

Course Prerequisite: Familiarity with vector analysis, techniques of solving 2^{nd} order linear homogeneous differential equations with constant coefficients; classification of singular points and theFrobenius method.

Course Outcome : Every branch of physics depends heavily on mathematical methods. Objective of this course is to enable to students
(i) to understand and apply the concept and techniques of linear vector spaces;
(ii) to understand and apply certain techniques of solving second order linear ordinary differential equation, including Sturm-Liouville theory and Green's functions;
(iii) to understand and apply the theory of functions of complex variables and to perform contour integration;
(iv) to learn various properties of special functions to be applied in most of the following courses of this program.

1. Linear Vector Spaces: Vector space, subspace, linear independence, dimension, inner product, norm, metric, Hilbert space, Linear Operators; Hermitian operators: matrix representation; change of basis; Eigenvalues and Eigenvectors, Similarity transformation: diagonalization; commutation and simultaneous eigenstates, complete set; commutator algebra. **14L**

2. Differential Equations occurring in Physics:Theory of second order linear homogeneous differential equations: a short review;Linear independence of solutions–Wronskian, finding the second solution. Sturm-Liouville theory; Hermitian operators; Completeness; Inhomogeneous differential equations - Green's functions. **16L**

3. Complex variables: Complex numbers, triangular inequalities, Schwarz inequality; Function of a complex variable - single and multiple-valued function, limit and continuity; Differentiation - Cauchy-Riemann equations and their applications; Analytic and harmonic function; Complex integrals, Cauchy's theorem (elementary proof only), converse of Cauchy's theorem, Cauchy's Integral Formula and its corollaries; Series – Taylor and Laurent expansion; Classification of singularities; Branch point and branch cut; Residue theorem and evaluation of some typical real integrals using this theorem. **18L**

4. Special Functions: Basic properties (recurrence and orthogonality relations, series expansion and generating function) of Bessel, Legendre, Hermite and Laguerre functions. Confluent hypergeometric functions. **12L**

Recommended Books:

1. Mathematical Methods for Physics and Engineering: A Comprehensive Guide 3rd Edition, K. F. Riley, M. P. Hobson, S. J. Bence, Cambridge
2. Mathematical Methods for Physicists: A Comprehensive Guide 7th Edition. G. B. Arfken, H. J. Weber, Frank E. Harris, Academic Press
3. Mathematics for Physicists, Denney and Krzywicki, Dover
4. Vector Spaces and matrices, R.M. Thrall, L. Tornheim, Dover
5. Introduction to Matrices and Linear Transformation, D.T. Finkbeiner, Courier Corporation
6. Complex Variables 2nd ed., Spiegel, Lipscutz, Schiller & Spellman, Schaum's Outline Series, McGraw Hill
7. Linear Algebra 4th ed., Lipschutz& Lipson, Schaum's Outline Series, McGraw Hill

PHS2PCOR02T: Analytical Dynamics 60 Lectures

Course Prerequisite: Familiarity with Newtonian mechanics; ability of solving equations of motion for simple force laws; familiarity with conservation principles; central force problem; elementary rigid body dynamics.

Course outcome: To enable the student
(i) grasp the fundamental principles of Mechanics, and
(ii) apply those principles in different branches of Physics;
(iii) learn the analytic formulations of Mechanics which can be applied beyond the classical regime;
(iv) learn elements of nonlinear dynamics.

1. Brief Review: Newtonian mechanics of a particle and of a system of particles – conservation principles; work-energy theorem and concept of kinetic and potential energies; critical look back into Newton's laws.Constrained motions – classification of constraints; forces of constraints; Virtual displacement and principle of virtual work; D'Alembert's principle; Lagrange's equations of first kind; examples of spherical pendulum and Atwood's machine. Generalized coordinates and velocities – Lagrange's equations of second kind; generalized force and generalized momenta, cyclic coordinates; Symmetries and conservation principles for energy, momentum and angular momentum; invariance under Galilean transformation. Case of velocity dependent potentials; rotating frame – Foucault's pendulum. **12L**

2. Hamilton's principle; rudimentary techniques of calculus of variation –shortest path connecting two points in a plane; the brachistochrone problem; Lagrange's equation from Hamilton's principle; merit of the variational formulation. **6L**

3. Two-body Central force problem– reduction to one-body problem; equations of motion and constants of motion; the equivalent one-dimensional problem– nature of orbits for inverse square force field; differential equation of orbits– classification of orbits; Runge-Lenz vector; Rutherford scattering. **8L**

4. Rigid bodies: Independent coordinates, orthogonal transformations and rotations (finite and infinitesimal), Euler's theorem, Euler angles, Inertia tensor and principal axis system, Euler's equations, Heavy symmetrical top with precession and nutation. **12L**

5. Hamiltonian as a Legendre transform– Hamilton's equations of motion; cyclic coordinates and conservation theorems. Derivation of Hamilton's equations from a variational principle. Canonical transformations and the concept of integrability; Generating functions, examples of canonical transformations, Poisson brackets, Infinitesimal canonical transformations, Conservation theorem in Poisson bracket formalism, Jacobi's identity, Angular momentum Poisson bracket relations. **12L**

6. Hamilton Jacobi theory: The Hamilton-Jacobi equation for Hamilton's principle function; The harmonic oscillator problem; Hamilton's characteristic function; Action angle variables. **6L**

7. Non-linear Dynamics: Continuous time dynamical system: fixed points. One dimensional dynamical system, geometric and algebraic analysis of stability of a fixed point, Phase portrait, One dimensional bifurcations, two dimensional Linear system, classification of the fixed points based on the eigenvalues of the Jacobian matrix, phase portrait. **4L**

Recommended Books:

1. Classical Mechanics, 3rd ed., Herbert Goldstein, Pearson Education.
2. Classical Mechanics, N.C. Rana and P.S. Joge, Tata-McGraw-Hill Education.
3. Classical Mechanics: A Course of Lectures, A. K. Raychaudhuri; OUP India
4. Mechanics, 3rd ed., Keith R. Symon, Pearson.
5. Theoretical Mechanics, M. R. Spiegel, Schaum's Outline Series, McGraw Hill
6. Mechanics, L.D. Landau & E.M. Lifshitz (Volume 1 of A Course of Theoretical Physics), Pergamon Press.
7. Nonlinear Dynamics and Chaos: S.H. Strogatz.

PHS2PCOR03T: Introductory Quantum Mechanics 60 Lectures

Course Prerequisite: Basic understanding in early quantum theory, wave function. Schrödinger equation-solution of bound state problems in 1D. Students are also expected to have some rudimentary exposure to Linear vector spaces.

Course Outcome: Students will
(i) know and understand the postulatory approach of quantum mechanics.
(ii) be able to deal with the angular momentum operator and its wave-function.
(iii) be able to solve bound state problems in three dimension in central field potential.
(iv) be able to solve problems in stationary and time dependent perturbation techniques as well as using variational techniques.

1. Basics of Quantum mechanics: Postulates of Quantum Mechanics; States of a system as Vectors and dynamical variables as operators, Canonical commutation relations, coordinate and momentum representations, time development in Schrödinger and Heisenberg pictures, the uncertainty relations. **8L**

2. One dimensional linear Harmonic Oscillator using raising and lowering operator. **4L**

3. Rotation and Angular Momentum in Quantum Mechanics: Orbital Angular Momentum, Angular Momentum as generator of infinitesimal rotations. Raising and Lowering operators, eigenvalues and expectation values; vector model of atom; Matrix representation of the angular momentum operators, Addition of angular momenta; Clebsch-Gordan Coefficients. **14L**

4. Bound State Central Field problems in three dimensions. **8L**

5. Approximate methods for stationery states: Time-independent perturbation: Non degenerate and degenerate perturbation. **9L**

6. Approximate methods for time dependent problems: Solvable two level system, time dependent perturbation theory, interaction picture and Dyson series; The adiabatic and sudden approximations. **8L**

7. The variational technique: harmonic oscillator & hydrogen atom problem; variational principle; H_2^+ molecule and H_2Ground state of the He atom. **9L**

Recommended Books:

1. Elements of Quantum Mechanics, B. Dutta Roy, New Age
2. Quantum Mechanics: Concepts and Applications, N. Zettili, John Wiley
3. Quantum Mechanics (Schaum's outline series), 2nd ed., Peleg, Pnini, Zaarur and Hecht, McGraw-Hill
4. Quantum Mechanicsy, C. Cohen-Tannoudji, B. Diu, F. Laloe, Wiley VCH
5. Quantum Mechanics, L. Schiff, McGraw-Hill
6. Vector Spaces and matrices, R.M. Thrall, L. Tornheim, Dover
7. Introduction to Matrices and Linear Transformation, D.T. Finkbeiner, Courier Corporation
8. Introduction to Quantum Mechanics, 2nd ed., D.J. Gritffith, Pearson

PHS2PCOR04T: Elements of Statistical Physics 60 Lectures

Course Prerequisite: Concept of thermodynamic variables, equation of state, thermodynamic equilibrium, quasi-static processes, reversible and irreversible transformation; Knowledge of laws of thermodynamics, thermodynamic potentials, and their applications.

Course outcome: To enable the student
(i) apply the principles of Statistical Mechanics in solving various problems related to different branches of Physics;
(ii) develop the ability to formulate and solve problems involving many degrees of freedom that draw recent research interest in the area of Statistical Mechanics;
(iii) handle non-equilibrium statistical systems;
(iv) learn the basic concepts of phase transitions.

1. Elements of Statistical Physics: Relevance of statistics in the mechanics of a system: macrostates, microstates, probability, phase space and ensemble; postulate of equal a priori probability (PEAP); ergodic hypothesis; Microcanonical ensemble; the no. of microstates in the phase space, entropy $S=k\ln\Omega$; Liouville's theorem. Entropy of ideal gas; Gibbs' Paradox. **6L**

2. Canonical and Grand Canonical systems: heat reservoir; partition function, entropy, equation of state; Energy fluctuation and C_v; Canonical distribution using Lagrange's undetermined multipliers; Applications – two level system, a system of harmonic oscillators, paramagnetic gas. Diffusive interaction- chemical potential; grand partition function; Equation of state; q-potential; Fluctuation in the number of particles; $PV=kT \ln Z$ relation. Application to ideal gas, chemical equilibrium and Saha Ionization formula. **13L**

3.Elements of Quantum statistical mechanics: Density Matrix; Quantum Liouville theorem; Density matrices for microcanonical, canonical and grand canonical systems; Simple examples of density matrices-one electron in a magnetic field, particle in a box; Indistinguishable particles: B-E and F-D distributions. **7L**

4. Ideal Bose and Fermi gas: Equation of state of Bose gas; B-E statistics; Bose condensation and thermodynamic behaviour; applications – blackbody radiation, Stefan-Boltzmann law; Equation of state of ideal Fermi gas; F-D statistics; Fermi gas at finite T. Degenerate Fermi gas; concept of Fermi energy; Low temperature specific heat of electron gas. **14L**

5. Elements of non-equilibrium Statistical Mechanics: Introduction to non-equilibrium phenomena; Derivation of Boltzmann equation – without and with collision; Boltzmann equation for quantum statistics; equilibrium distribution; approach to equilibrium; Transport phenomena: Boltzmann transport equation; relaxation time approximation; electrical conductivity; generalized form for transport coefficients. **10L**

6.Elements of Phase Transition: Phase transitions-first order and continuous, order parameter; Ising model-partition function for one dimensional case, critical phenomena and critical exponents; Scaling; Landau's theory of phase transition; calculation of exponents from Landau's theory; upper critical dimension. **10L**

Recommended Books:

1. Statistical Mechanics, 2nd ed., R. K. Pathria, Butterworth Heinmann
2. Thermodynamics and Statistical Mechanics, W. Greiner, L. Neise and H. Stocker, Springer
3. Statistical Mechanics, 2nd ed., K. Huang, John Wiley
4. An Introductory Course of Statistical Mechanics, Palsh B. Pal, Narosa
5. Equilibrium Statistical Physics, 3rd ed., M. Plischke and B. Begersen, World Scientific
6. Fundamentals of Statistical and Thermal Physics, F. Reif, McGraw Hill
7. Statistical Mechanics of Phase Transitions, J. M. Yeomans, Oxford

PHS2PCOR05P: General and Computational Lab I 120 Class Hours

Unit I: General Lab I

Course Outcome: Student gets trained
i) in performing experiments and recording data on reasonably state of the art equipment,
ii) in analyzing data to draw the final conclusions.

The experiments are so chosen so as to give them maximum exposure to fascinating field of experimental physics based on the theoretical knowledge acquired by the student. To encourage students in critically reviewing the results, experimental set-up and procedure, rather than merely performing standard experiments.

List of experiments:

1) Determination of Hall coefficient of p and/or n type semiconductor
2) Frank-Hertz experiment
3) Determination of e/m of electron
4) Determination of Dielectric Constant of a non-polar organic liquid
5) Transfer Characteristic of Enhancement type MOSFET

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* Some more experiments may be introduced as and when available.

Unit II: Computational Physics Lab I

Course Outcome: Since familiarity at the fundamental level with the logical structure and grammar and syntax of any computer language can enable the student to quickly change, if necessary, to any other, we shall generally concentrate on one such language. Target is to inculcate the ability to write programs by the students themselves for understanding different concepts and solving different problems of physics. Each year problem sets need to be different.
Language to be used for learning the following basic principles is Python. Latex is also included in this course to familiarize the students with scientific typesetting technique.
Students has to develop programs.

- Latex : document preparation
- Student will write programs on the following topics:

  1. Sympy

2. Simulation of 1-D logistic map orbit for different values of r
   . (Start from different initial value of x to observe the fixed point(s))
   a. Study of 2 and 4 period, Chaos (Sensitive dependence on initial condition- graphical observation and Liapunov Coefficient).

   Orbit diagram for 1-D logistic map and 1 D Tent Map.

   Curve fitting: Linear least square fit, linearizable least square fit, gradient descent.

   Matrix: Gaussian elimination, Gauss Jordan Elimination, Determinant, System of Linear Equation, Inverse of a matrix.

   Eigenvalue by Power method and Jacobi method.

Recommended Books:

1. Computational Physics: Problem Solving with Python, 3rd Edition Rubin H. Landau, Manuel J Páez, Cristian C. Bordeianu
2. Introduction to Python for Science and Engineering (Series in Computational Physics), David J. Pine, CRC Press

PHS2PAEC01M: Machine Learning and its Application in Physics

30 Class Hours

Course Outcome: Machine learning is a relatively new set of techniques which are being used in Physics widely in recent years. These techniques are essential component of artificial intelligence. Familiarity with the basic concepts of Artificial Neural Network, Classification, regression, clustering and Deep learning will empower the students with tools to solve problems of Physics. Moreover a basic knowledge of Machine learning will help the students to find employability outside the conventional boundaries of Physics.

Course Content and Instructions:

• This course is a mixture of lecture and hands-on practice with python Tensorflow/Pytorch.

• Students will be evaluated on written/viva examination on the theory but they will also have to implement the assignments involving coding and analysis based on the following syllabus. Problems should be selected from different domains of Physics.

• For Classification and Clustering use of available datasets are encouraged while for regression problems should be attempted on synthetic noisy data.

1. Machine learning– Artificial Neural Network– Bio-inspired origin and wide scope of applications.

2. Supervised learning : Classification and regression;
   Perceptron, perceptron learning rule, convergence, limitation;
   Multilayer Perceptron, output functions (sigmoidal, tanh, RELU),
   Measure of error – sum of square deviations, cross entropy,
   Error back propagation. Hyper-parameters: Number of hidden layers, number of neurons in each layer.
   Data partition – training/ testing/ validation and the idea of cross validation.

3. Deep learning: Idea of convolutional Neural network. Huper-parameters: Size and Number of convolution filers in each layer.

4. Physics Informed Neural Network – Trajectory matching with incomplete data.

5. Clustering– K means clustering in 2 and higher dimension. Measure of clustering – Mahalanobis distance.

Book and References:

1. https://machine-learning-for-physicists.org/?fbclid=IwAR19C6lkfpGa4Fys54VMvMgW7xxaj7t6qkyt2MK4G4_IXL-mIMwOlx98zqc
2. A high-bias, low-variance introduction to Machine Learning for physicists, physics>arXiv:1803.08823
3. Machine Learning for Physicists: https://doi.org/10.1088/978-0-7503-4957-4

Semester II

PHS2PCOR06T: Classical Theory of Fields and Electrodynamics 60 Lectures

Course outcome: To familiarize the learner with the techniques of field theoretic study that forms the core of many advanced topics in Physics, e.g., Quantum field theory, Nuclear Physics, Condensed Matter Physics, General Relativity and so on. The student should be able to understand and apply the concepts of Electrodynamics. The student should develop an understanding of the basics of electromagnetic (EM) radiation and relativistic nature of EM-field.

1. Principles of Galilean relativity and Special Relativity, Notion of space-time interval, simultaneity and coincidence, Transformation of coordinates and velocities, curvilinear coordinates and tensors; Tensors as geometrical objects. **10L**

2. Dynamics of a relativistic free particle through action principle and symmetries, Interaction of a charged particle with a four-vector field, identification of electromagnetic field tensor and its gauge symmetry and conservation law, Lorentz-force equation. **10L**

3. Generalization of particle mechanics to field theory and field theoretic action for a scalar field; Dynamics of a four-vector field and Maxwell's field equations. **6L**

4. Noether theorem and Symmetries, Space-time symmetries of Real scalar field, Global and Local Gauge symmetries of Complex scalar field and introduction of gauge field to restore local gauge symmetry, Covariant derivative. **8L**

[**Note:** In items 1-4 above, everything has to be done in covariant notation demonstrating their connection to the three-vector notation.]

5. Wave equations for vector and scalar potential and solution, Retarded potential and Lienard-Wiechert potential, Electric and Magnetic fields due to uniformly moving charges and an accelerated charge, Linear and circular acceleration and angular distribution of power radiated, Bremsstrahlung, Synchrotron and Cerenkov radiation, Reaction force of radiation. **26L**

Recommended Books:

1. Classical Theory of Fields, L.D. Landau & E.M. Lifshitz (Volume 2 of A Course of Theoretical Physics) Pergamon Press.
2. Gravitation: Foundations and Frontiers, 1st ed., Thanu Padmanabhan, Cambridge University Press.
3. Introduction to Electrodynamics, 3rd ed., David J. Griffths, Prentice-Hall of India.
4. Classical Electrodynamics, 3rd ed., J. D. Jackson, Wiley
5. Classical Electromagnetic Radiation, 3rd ed., M. A. Heald and J. B. Marion, Saunders College Publishing .

PHS2PCOR07T: Condensed Matter Physics 60 Lectures

Course prerequisite: Familiarity with methods of classical, quantum and statistical mechanics at the basic level.

Course outcome: To familiarize the learner with the basic facts and underlying principles which form the back-bone of Condensed Matter Physics. To develop the skill of formulating and systematically solving problems in Condensed Matter Physics that will find applications in Material Physics as well as in other related branches of Physics.

1. Chemical Bonding in solids: Idea of molecular bonding; the Lennard-Jones potential; Ionic bonding in alkali halides; covalent bonding; bonding and anti-bonding orbitals in H_2^+; directional property of covalent bonds in solids; tetrahedral coordination in Carbon via sp^3 hybridization; metallic bonding, The van der Waals bonding – the noble gases; the hydrogen bond– ice crystal; Cohesive energy and bulk modulus; examples of alkali halides, Madelung constant. **5L**

2. Structure of solid matter: Crystal structure- Bravais lattice and primitive vectors, Conventional unit cell, primitive unit cell and Wigner-Seitz cell, point symmetry, 32 crystal classes (Point groups), concept of basis and space group; simple crystal structures, lattice planes and Miller indices, Reciprocal lattice and Brillouin zone, Bragg's interpretation of Laue condition, structure factor, x-ray diffraction- Laue, Rotating crystal, powder, electron and neutron diffraction by crystals, Surface crystallography. **7L**

3. Free electron in Solids: Drude theory of metals– basic assumption, free electron gas in an infinite square-well potential, Fermi gas at T=0 K, Fermi-Dirac Statistics, Density of allowed wave vectors, Fermi momentum, energy and Temperature, ground state energy and bulk modulus, specific heat capacity of electrons in metals. **6L**

4. Electronic band structure of solids: Failures of free electron theory, Periodic potential and Bloch's theorem; Symmetry of dispersion relation of a band electron; Band theory – nearly free electrons, band gap, number of states in a band; tight binding approximation; other methods of calculating band structures; semi-classical dynamics of electrons in a band; Landau levels– de Haas van Alphen effect. **10L**

5. Semiconductors: General properties and examples of semiconductors, effective mass- cyclotron resonance, charge carrier density in intrinsic semiconductors – statistics, Doping, carrier density in doped semiconductors – statistics, impurity band conduction, p-n junction, metal-semiconductor Schottky contact, heterostructures and superlattices. **5L**

6. Dynamics of atoms in a crystal: Failures of the static model, Classical theory of lattice vibration under harmonic approximation, the monatomic and diatomic linear lattices, acoustic and optical modes, long wavelength limits, Adiabatic approximations, Quantum theory of the harmonic crystal- normal modes and phonons, phonon statistics, high and low temperature specific heat, Models of Debye and Einstein, comparison with electronic specific heat, effects due to anharmonocity – thermal expansion and heat conduction by phonons. **6L**

7. Magnetism : Origin, Larmor diamagnetism and Langevin paramagnetism, Curie's law; effective Borh magneton; Hund's rule; crystal field and orbital quenching; Pauli paramagnetism, Landau diamagnetism; Nuclear magnetic resonance – probe for magnetic structures, ESR, exchange interaction – inadequacy of dipolar interaction; electrostatic origin of exchange interactions, magnetic interactions in the free electron gas, Heisenberg model, Ferromagnetism: exact ferromagnetic ground state at $T=0$; excitation of magnons at $T>0$ (qualitative); Weiss molecular field theory; ferromagnetic domains; anti-ferromagnetism and ferrimagnetism: spinel structure. **8L**

8. Superconductivity: Phenomenological description– critical temperature, persistent current, Meissner effect; Thermodynamics of superconducting transition; The two-fluid model; London equation; Type I and II superconductors; the BCS ground state (qualitative idea of phonon mediated pairing), Quantization of magnetic flux and Josephson effect, high T_C superconductors (informative only). **7L**

9. Dielectric properties of materials: Dielectric function, orientational polarizability, Classical theory of electronic and ionic polarization, optical absorption, Piezoelectricity, Spectroscopy with electrons and phonons, Optical properties of ionic crystals in infrared regime. **6L**

Recommended Books:

1. Elementary Solid State Physics, M. Ali Omar, Pearson
2. Introduction to Solid State Physics, 8th ed., C. Kittel, Wiley
3. Solid State Physics, N. Ashcroft and N.D. Mermin, Saunders College
4. Principles of the Theory of Solids, 2nd ed., J. M. Ziman, Cambridge
5. Solid-State Physics, 4th ed., H. Ibach and H. Luth, Springer
6. Band Theory and Electronic Properties of Solids (Oxford Master Series in Condensed Matter Physics), John Singleton, Oxford
7. Magnetism in Condensed Matter (Oxford Master Series in Condensed Matter Physics), Stephen Blundell, Oxford
8. Physics of Semiconductor Devices, 3rd. ed., S. M. Sze and K. K. Ng, Wiley
9. Electrionic Properties of Materials, 3rd ed., R. E. Hummel, Springer
10. Introduction to Superconductivity, 2nd ed., A. C. Rose-Innes and E. H. Rhoderick, Pergamon Press

PHS2PCOR08T: Applications of Quantum Mechanics **60 Lectures**

Course Outcome: The objective of this course is to enable the students (i) to apply quantum mechanics in studying atomic physics of increasing complexities; (ii) to learn WKB approximation, an important tool to be applied in many application of atomic, molecular and nuclear physics; (iii) to learn the techniques of scattering problems in quantum mechanics: to be applied in various branches of modern nuclear and subatomic physics.

1. Hydrogen Spectrum: Review of basic concepts – expectation value of r^k for an *nlm* state; hydrogenic atom in an em field – transition rates – absorption – stimulated emission; the dipole approximation; Selection rules for one electron atom – magnetic dipole and electric quadrupole transition ; line shapes and width – pressure and Doppler broadening. **12L**

2. Relativistic correction terms for a one electron atom – fine structure of hydrogenic atoms, hyperfine interactions- hyperfine structure – magnetic dipolar and quadrupolar hyperfine splitting – isotope shift. **10L**

3. Atoms in electric and Magnetic field - Normal and anomalous Zeeman effect; Paschen-Back effect; Stark effect. **8L**

4. The quantum theory of scattering: the green's function, the Born approximation, the Lippman-Schwinger formalism, the partial wave approach, phase shifts, scattering length, resonances, the Eikonel approximation. **20L**

5. Approximate methods for stationery states: WKB approximation. **10L**

Books Recommended:

1. Elements of Quantum Mechanics, B. Dutta Roy, New Age
2. Quantum Mechanics: Concepts and Applications, N. Zettili, Wiley
3. Quantum Mechanics (Schaum's outline series), 2nd ed., Peleg, Pnini, Zaarur and Hecht, McGraw-Hill
4. Quantum Mechanicsy, C. Cohen-Tannoudji, B. Diu, F. Laloe, Wiley VCH
5. Quantum Mechanics, L. Schiff, McGrow-Hills
6. Introduction to Quantum Mechanics, D.J. Gritffith, D.F. Scröfter, Cambridge University Press
7. Physics of Atoms and Molecules, 2nd Edition , B.H. Brandsden C. J. Joachain, Pearsonon

PHS2PCOR09T: Exposure to Astronomy and Material Physics   60 Lectures

Course Prerequisite: Familiarity with Classical and Quantum Mechanics, Electromagnetism, Elementary Optics and Elementary Solid State Physics.

Unit I: Astronomy

Course Outcome**:** Students will be introduced to

i) basic practical tools, methods and phenomena that underlies Astronomical observations;
ii) basics of Astrometry
iii) quantitative aspects of electromagnetic spectrum;
iv) telescopes in all wavebands;
v) Statistics of measurements, and
vi) Astronomy beyond photons.

1. Astronomy through the ages: Technology through the centuries, observation vis-à-vis theory. **1L**

2. Multi-messenger Astronomy: Electromagnetic channel – EM frequency bands, Photons in atmosphere and interstellar medium; non-photon astronomy – meteorites, cosmic rays, neutrino, gravitational waves. **3L**

3. Coordinate systems and charts: Various coordinates in celestial sphere and solid angles; Surveys, Charts and Catalogues. **4L**

4. Celestial motion and time: Apparent motion of stars - annual motion of the earth, parallax, stellar aberration, Precession of the Earth; Proper and peculiar motion of stars, Lunar and planetary motion, Eclipse of the Sun and Moon, Measurement of time. **10L**

5. Telescopes: Telescopes and antennas, Intensity and polarisation as function of time, frequency distribution; Common configurations of optical telescopes, focal length and aperture, plate scale, sensitivity and resolving power of a telescope; usage of non-focusing instruments in gamma-ray and x-ray astronomy, Antenna beams, point-spread function, diffraction limiting the radio resolution. **6L**

6. Detectors and Statistical Methods of Data Analysis: Detectors – Photomultiplier, Proportional counter, Charge-coupled device; Statistics of measurements – noise, fluctuations, Poisson and Normal distribution, Variance and standard deviation, measurement significance, statistical traps, Background and its subtraction, Comparison to theory (Least-square fit and Chi square fit). **6L**

Recommended Books:

1. Astronomy Methods, Hale Bradt, 1st Edition, Cambridge University Press
2. An Introduction to Distance Measurement in Astronomy, Richard de Grijs, John Wiley & Sons
3. A Practical Guide to Observational Astronomy, M. Shane Burns, CRC Press, Taylor & Francis Group.

Unit II: Material Physics

Course Outcome**:** Students will be introduced to
i) Different classes of materials and their uses;
ii) Schematic band diagrams of different crystalline materials;
iii) Overview of semiconductor physics;
iv) Develop familiarity with sample preparation.

1. Classification of materials: many phases matter; solids– crystalline and anamorphous; symmetries of crystalline phase; space and point groups (rudimentary level); alloys – phase diagrams; quasi-crystalline system; liquid crystals; nano-crystalline materials. **6L**

2. Electronic structure of solids: Recapitulations of free electron dispersion in metals and elementary concept of energy bands in periodic solids; classification of solids on the basis of band picture; concept of holes; Band structures of some typical metals and semiconductors, e.g. Al, Cu, Si (non-quantitative). **6L**

3. Semiconductors: Temperature dependence of carrier density in an intrinsic semiconductor; conductivity; extrinsic semiconductors– p- and n-type; schematic band diagrams; schematic variation of carrier density with temperature; conductivity; effective mass of carriers; Hall effect in doped semiconductors. Semiconductor devices (qualitative): metal-semiconductor junction (schematic band diagram); Schottky barrier contacts; p-n junctions (schematic band diagram); Zener diode; photodiode; tunnel diode; BJT and MoSFET. **10L**

4. Synthesis and Characterization of materials: Method of growing single crystals – Czochraski method, float zone method, Bridgman method; Methods of solid state reactions: examples; sol-gel techniques; chemical vapour deposition; sputtering. XRD; electrical, optical and magnetic measurements. **8L**

Recommended Books:

1. Electronic Properties of Materials, 4th ed., R. E. Hummel, Springer
2. Understanding Materials Science, 2nd ed., R. E. Hummel, Springer
3. Solid State Chemistry and its Applications, 2nd ed., A. R. West, Wiley
4. Introduction to Solid State Physics, 8th ed., John C. Kittel, Wiley
5. Principles of condensed matter physics, P. M. Chaikin and T. C. Lubensky, Cambridge University Press
6. Introduction to Magnetic Materials, 2nd ed., B. D. Cullity and C. D. Graham, Wiley
7. Elements of X-Ray Diffraction, 3rd ed., B. D. Cullity and S. R. Stock, Pearson College

PHS2PCOR10P : General and Computational Lab II 120 Class Hours

Unit I : General Lab II

Course Outcome: To introduce experiments in modern physics which are related to the domain of theoretical knowledge of the student. To give exposure to techniques of determination of fundamental constants and basic measurement techniques in modern physics. Emphasis to be given on critically reviewing the results, experimental set-up and procedure, rather than merely performing standard experiments. Student is to be encouraged to think of alternative experimental design of their own.

1. Band gap measurement in a semiconductor using Four Probe method
2. Determination of Ferromagnetic-Paramagnetic transition temperature of Ferrite
3. Study of dispersion relation of elastic waves in monatomic and diatomic lattices by using analogous electrical circuits.
4. Verification of Wiedemann-Frantz Law in metals
5. Determination of e/m electron by magnetic focusing method
6. Determination of Planck's constant using a LED
7. Particle size estimation using diffraction

* Some more experiments may be introduced as and when available.

Unit II: Computational Lab II

Course Outcome: Students will be able (i) to model a physical problem in terms of mathematical formulation and subsequent code development and explore the properties of the model by simulation. This course is focussed on deterministic simulation.

1. Simulation of Simple harmonic Motion : damping – periodic forcing: Amplitude and Velocity resonance.
2. Simulation of anharmonic oscillator with force $F(x) = -m\omega^2 x^p$ when p is an odd integer, Amplitude Frequency plot.
3. Simulation of pendulum $F(x) = -m\omega^2 \, sin \, sin \, x$. Velocity and amplitude resonance under periodic forcing. Chaos.
4. Simulation of Oscillation under Lennard-Jones Potential $V(x) = \epsilon\left[\left(\frac{\sigma}{x}\right)^{12} - \left(\frac{\sigma}{x}\right)^{6}\right]$ around the equilibrium point.
5. Solution of Schrödinger equation : particle in a box, particle in a finite well, 1-D Linear harmonic oscillator, 1 D motion under potential $V(x) = \lambda|x|$.
6. Solution of Partial differential equation – a) Laplace equation b) Poisson's equation with given charge density both under Dirichlet condition

Recommended Books:

1. Introduction to Computational Physics : Tao Pang, Cambridge University Press
2. Computational Physics: Problem Solving with Computers : R.H. Landau, Wiley-Interscience

Semester III

PHS2PCOR11T: Elements of Spectroscopy **60 Lectures**

To be detailed later

PHS2PCOR12T: Advanced Quantum Mechanics **60 Lectures**

To be detailed later

PHS2PCOR13P: General and Computational Lab III **120 Class Hours**

Unit I: General Laboratory III

To be detailed later

Unit II: Computational Lab III

To be detailed later

PHS2PDSE01T **60 Lectures**

a) Advanced Condensed Matter Physics I

To be detailed later

b) Astrophysics I

To be detailed later

PHS2PCOR14M: Seminar Presentation **60 Class Hours**

To be detailed later

PHS2PSEC01M: Physics Teaching Skill **60 Class Hours**

To be detailed later

Semester IV

PHS2PCOR15M: Problem Solving Techniques in Physics 60 Class Hours

To be detailed later

PHS2PDSE02T 60 Lectures

a) Quantum Field Theory

To be detailed later

b) Nonlinear Dynamics

To be detailed later

PHS2PDSE03T 60 Lectures

a) Advanced Condensed Matter Physics II

To be detailed later

b) Astrophysics II

To be detailed later

PHS2PDSE04P **120 Class Hours**

(a) Advanced Condensed Matter Physics Lab

To be detailed later

(b) Astrophysics Lab

To be detailed later

PHS2PCOR16M: Project Literature Review

To be detailed later

PHS2PCOR17M: Project Dissertation

To be detailed later